Euro Polymer Science 2019: Recent Developments in Graphene Oxide/Epoxy Carbon Fiber-Reinforced Composites - James Njuguna-Robert Gordon University

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The two-dimensional macro molecule graphene and its derivatives have widely been investigated for their application as nanofiller in carbon fiber-reinforced composites (CFRC). Research has progressed from techniques that disperse graphene as a mixing constituent within the composite material to more complex examples where graphene is covalently bonded to fiber, matrix or both via multiple reaction steps. This field of research is multi-disciplinary whereby branches of materials, engineering, polymer science, physics and chemistry often overlap. From the materials engineering perspective, the desire is to discover the novel materials targeting industrial applications and obtain a full understanding of the graphene oxide chemistry and interaction of graphene oxide with a polymer matrix. To date, most of the research is targeted at (i) improving the fiber/matrix interface properties and/or (ii) improving the dispersion of nanofiller within the matrix; both factors ultimately improve composite performance. Organizing that information critically can lead to emergence of a generalization of material design. Therefore, the objective of this work is to critically review current state of art in the field of graphene oxide/epoxy CFRCs and propose the design rules based on current scientific trend and common themes for future works.

Synthesis Techniques for Graphene and its Derivatives

Nanofiller materials for use in industrial CFRC need to meet certain minimum criteria. Production of nanofiller must be attainable at large scales and produce materials possessing properties which facilitate simple processing techniques. This enables the production of nanofiller/CFRCs with minimal process unit operations and cost efficiently.

Types of Graphene Oxide

It is important that materials engineers recognize the significant differences between GO and other nanofiller materials such as traditional organic polymers (e.g., starch and cellulose), nanoclays and metallic nanoparticles. Critically, GO is a macromolecule composed of non-stoichiometric amounts of carbon, oxygen and hydrogen. Therefore, there is a wide variance in GO forms and this factor is frequently not given consideration by researchers when constructing nanocomposites shows typical morphology of GO and experimentation has shown (Muzyka et al., 2017) that there are considerable variations in GO chemistry with different versions of the Hummers method of preparation.

Surface Modification of Carbon Fiber

Atoms within the body of a uniform three-dimensional solid material such as diamond are bonded together with each carbon atom interacting covalently with four neighbouring atoms. However, at the solid material surface there is an interface where the three-dimensional structure ceases to exist. Atoms on the surface are less tightly bound because they are surrounded by less neighbouring atoms. These atoms have free valence electrons, and this creates a surface energy density. The fact that surface energy exists is intuitive when considering the paradoxical scenario where the surface was less energetic than the solid body.

GO/Epoxy Resin Matrix

The epoxy resin is a type of polymer characterized often with one or more epoxide functional group with at least one of the epoxide functional group acting as a monomer and terminal unit of the polymer within the structural chain. Epoxy resins are extensively used in the production of lightweight carbon fiber-reinforced composites (CRFP) to deliver desired engineering properties such as high modulus and strength, low creep, superb chemical and thermal stability. The epoxy/carbon fiber-reinforced composite design, just like any other composite, is heavily dependent on the mechanical and thermal properties of the resulting composites of the manufactured epoxy/carbon fiber-reinforced composite withstanding the conditions set by its application requirements.

Graphene /Epoxy Carbon Fiber-Reinforced Composites

The most exciting area of current research is in multi-scale modification of carbon fiber/epoxy composites with graphene based nano materials. Many unique graphene properties have made it an ideal candidate for improving polymer properties of CFRC. The addition of nanofillers into the resin system during composite manufacturing can directly influence the mechanical, thermal and chemical properties of the resulting composite. In turn this increase, e.g., the strength, dimensional properties and hence extend the functional life of the material although graphene nanofillers remain extremely expensive the addition of small amounts is known to improve the mechanical qualities of a composite.

Future Perspective/Outlook

The CFRP industry is well-established with many applications across a range of industries which have a need for ultra-strong and low-weight materials. With this existing demand there is a latent need for continued improvement as companies compete to deliver more technologically advanced solutions. In addition to this, future demand for CFRP is likely to evolve at an ever-increasing rate. The Species has a growing desire to explore the solar system and make space accessible to the public and the economics of this industry rely heavily on ultra-strong and low-weight materials. In addition, the public are becoming more aware of the impact that the species has on the planet.

Considering our finite resources of materials and the huge energy costs involved in producing metals then there will be an ever-increasing drive to utilize novel and more environmentally friendly materials in the future. Research and development within the materials science field is crucial to meeting the future demands and graphene-based materials have a role to play.

Conclusion:

This work covers recent advances in carbon fiber, epoxy and graphene composite nanomaterials. We have explored the graphene derivatives, synthesis techniques and identifying popular methods utilized in CFRC. The primary focus on tailoring for the mechanical properties through the carbon fiber surface modification, epoxy polymer modification (covalent and non-covalent), composite processing techniques and nanofiller dispersion in epoxy. It is shown that GO dispersions challenges are the bottleneck on polymer modification in that it improves its compatibility with carbon fiber and hence, enhances mechanical properties through improved compatibility with the carbon fiber reinforcement.

The covalent interaction between nanofillers-carbon fibers and nanofillers-matrix provides unique way to integrating all components of CFRC which is responsible for improved mechanical properties. It is also noted that carbon fiber sizing is a surface treatment which is often proprietary and commercially sensitive should also be incorporated in to control experiments in addition to analysis of un-sized fibers and epoxy. Significant studies have been conducted with success on to improve wettability and better intermolecular interactions at the interface improved mechanical properties. This work provides some excellent examples demonstrating how mechanical performance can be improved depending on modification technique, however it also validates that for engineering applications will require a compromise between properties and complexity (i.e., unit operations and processability) may be required.